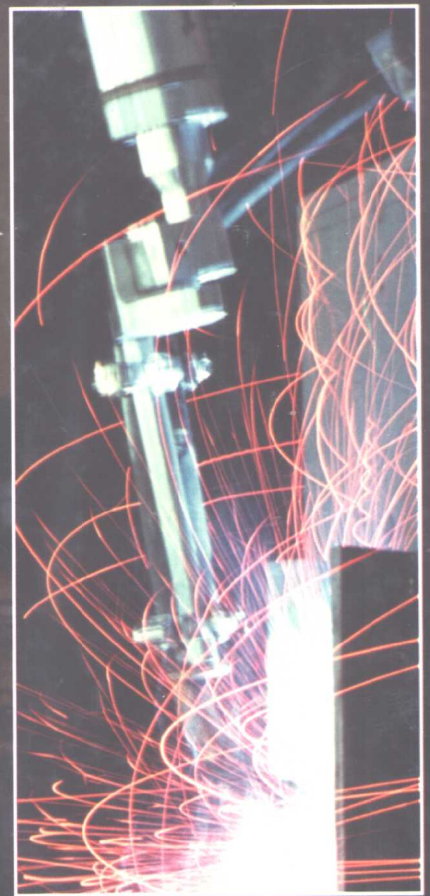


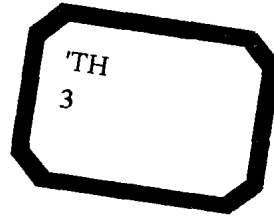
Manufacturing Engineering and Technology

FOURTH EDITION



Serope Kalpakjian • Steven R. Schmid

Manufacturing Engineering and Technology



Fourth Edition

Serope Kalpakjian

Illinois Institute of Technology

Steven R. Schmid

The University of Notre Dame



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To

Granddaughter
Carissa Ann Kalpakjian

and

Shelly Petronis

Preface

The field of manufacturing engineering and technology continues to advance rapidly, transcending disciplines and driving economic growth. This challenging and broad topic has continued to incorporate new concepts at an increasing rate, making manufacturing a dynamic and exciting field of study. In preparing this fourth edition, our most important goal throughout has been to provide a comprehensive state-of-the-art textbook on manufacturing, which also encompasses the additional aims of motivating and challenging students.

As in previous editions, the text presents topics with a balanced coverage of relevant fundamentals and real-world practices, so that the student develops an understanding of the important and often complex interrelationships among the many technical and economic factors involved in manufacturing.

This new edition basically follows the same introductory nature, format, organization, and balance as the third edition. It has retained its emphasis on (a) the influence of materials and processing parameters in understanding manufacturing processes and operations; (b) design considerations, product quality, and manufacturing cost factors; and (c) the domestic and global competitive context of each manufacturing process and operation, highlighted with illustrative examples.

STUDY AIDS

- Presentation of each topic within a larger context of manufacturing engineering and technology, using extensive schematic diagrams and flowcharts.
- Emphasis on the practical uses of the concepts and information presented.
- Analogies, discussions, and problems designed to stimulate the student's curiosity about consumer and industrial products and how they are manufactured.
- Extensive reference material, including numerous tables, illustrations, graphs, and bibliographies.
- Numerous illustrative examples and case studies to highlight important concepts and techniques.
- Tables comparing advantages and limitations of manufacturing processes.
- A summary, list of key terms, and concise description of current trends at the end of each chapter.

WHAT IS NEW IN THIS EDITION

- Several new examples and case studies have been added.
- There are now a total of almost 2,200 questions and problems, about a quarter of them new to this edition.
- Summaries at the end of each chapter have been completely rewritten and expanded.
- The bibliographies at the end of each chapter have been thoroughly updated.

- More cross-references have been made throughout the text to other sections and chapters in the book.
- New or expanded topics include the following:

Topic	Section	Topic	Section
Abrasive belts; microreplication	25.10	Micromachining	26.12
Atomic force microscope	31.5	Nanofabrication	26.11
Biodegradable plastics	7.8	Nanomaterials	6.15
Bundle drawing	15.11	Nanopowders	17.2
Carbon foam	8.6	Octree representation	39.4
Chemical mechanical polishing	25.10	Overmolding	18.3
Coatings	21.6	Plastics, common trade names	7.6
Compliant end effector	38.7	Porous aluminum	6.2
Conductive graphite fibers	9.2.1	Product liability examples	37.6
Deburring	25.11	Pulsed electrochemical machining	26.3
Diamond-like carbon coating	33.13	QS 9000 standard	36.4
Die failures	14.12	Rapid prototyping	Ch. 19
Die manufacturing methods	14.11	Reflow soldering	30.3
Electrically conducting adhesives	30.6	Robustness	36.6
Friction stir welding	28.4	Rotary ultrasonic machining	25.9
Hexapod machine tools	24.3	Superconductor processing	17.13
ISO 14000 standard	36.4	Taguchi loss function	36.6
Joining plastics	30.6	Thermal effects in machine tools	24.3
Laser interferometry	35.5	Titanic: brittle fracture example	2.10
Laser peening	33.2	Total productive maintenance	38.2
Linear motor drives for machine tools	24.3	Transfer/injection molding	18.12
Microencapsulated powders	17.21	Water-jet peening	32.2
Micrograin carbides	21.11	Wave soldering	30.3

In response to comments and suggestions by numerous reviewers, several major and minor changes have also been made throughout the text. A page-by-page comparison with the third edition will show that literally thousands of changes have been made for improved clarity and completeness.

AUDIENCE

As in the previous editions, this fourth edition has been written for students in mechanical, manufacturing, industrial, aerospace, and metallurgical and materials engineering programs. It is hoped that by reading and studying this book, students will come to appreciate the vital nature of manufacturing engineering as an academic subject that is as exciting, challenging, and important as any other engineering and technology discipline.

ACKNOWLEDGMENTS

This text, together with the first three editions, represents a total of almost ten years of effort; it could not have been written and produced without the help of many colleagues and former students. It gives us great pleasure to acknowledge the assistance of the following in the preparation and publication of this fourth edition.

We are very grateful to Marcia Horton, and Laura Curless, Prentice Hall, for their enthusiastic support, and to Rose Kernan for her supervision of this revision.

We gratefully acknowledge the following reviewers for sharing their knowledge with us and for their constructive criticisms and suggestions:

Our colleagues at the Illinois Institute of Technology: John Cesarone, Ali Cinar, Marek Dollar, Donald Duvall, Jerry Field, Craig Johnson, Marvin Levine, Keith McKee, Satish Parulekar, Mohamed Tarabishy, Bharat Thakkar, and Calvin Tszang.

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Finally, many thanks to Jean Kalpakjian for her help during the editing and production of this book.

Serope Kalpakjian
Steven R. Schmid

About the Authors

Professor Serope Kalpakjian has been teaching at the Illinois Institute of Technology since 1963. After graduating from Robert College (with High Honors), Harvard University, and the Massachusetts Institute of Technology, he joined Cincinnati Milacron, Inc., where he was a research supervisor in charge of advanced metal-forming processes. He has published numerous papers and is the author of several articles in encyclopedias and handbooks; he has also edited various volumes and serves on the editorial boards of several journals and the *Encyclopedia Americana*.

He is the author of three additional manufacturing books, two of which received the M. Eugene Merchant Manufacturing Textbook Award. He is a Life Fellow of the American Society of Mechanical Engineers, Fellow and Life Member of ASM International, and Fellow of the Society of Manufacturing Engineers, and is a full member (Emeritus) of the International Institution for Production Engineering Research (CIRP). He is a founding member and a past president of the North American manufacturing Research Institution.

Professor Kalpakjian has received several awards: Citation by the Forging Industry Educational and Research Foundation for best paper (1966); Citation by the Society of Carbide and Tool Engineers (1977); the “Excellence in Teaching Award” from the Illinois Institute of Technology (1970); the “Centennial Medallion” by the American Society of Mechanical Engineers (1980); the International “Education Award” by the Society of Manufacturing Engineers (1989); and the Albert Easton White Distinguished Teacher Award by the American Society for Metals International (2000).

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He is the author of over thirty technical papers in various journals, has edited three conference proceedings, has co-authored “Fundamentals of Machine Elements,” and has contributed two chapters to the CRC “Handbook of Modern Tribology.” He serves on the Tribology Division Executive Committee of the American Society of Mechanical Engineers, and has held officer positions in the Society of Manufacturing Engineers and the Society of Tribology and Lubrication Engineers. He is a registered Professional Engineer and a Certified Manufacturing Engineer.

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CONVERSION FACTOR FOR SI UNITS

PROPERTY	TO CONVERT FROM	TO	MULTIPLY BY
Acceleration	ft/s ²	m/s ²	3.048×10^{-1}
Angle	degree	rad	1.745×10^{-2}
	minute	rad	2.909×10^{-4}
	second	rad	4.848×10^{-6}
Area	in. ²	m ²	6.452×10^{-4}
	ft ²	m ²	9.290×10^{-2}
	in. ²	mm ²	6.452×10^2
	ft ²	mm ²	9.290×10^4
Density	lb/in. ³	kg/m ³	2.768×10^4
Energy	ft·lb	J	1.356
	Btu	J	1.054×10^3
	calorie	J	4.184
	watt·h	J	3.600×10^3
Force	kgf	N	9.807
	lb	N	4.448
Length	in.	m	2.540×10^{-2}
	ft	m	3.048×10^{-1}
Mass	lb	kg	4.536×10^{-1}
	tonne (metric)	kg	1.000×10^3
	ton (short)	kg	9.072×10^2
	hp	W	7.457×10^2
Power	Btu/min	W	1.757×10
	ft·lb/min	W	2.260×10^{-2}
	lb/in. ²	Pa	6.895×10^3
	bar	Pa	1.000×10^5
Pressure, stress	atmosphere	Pa	1.013×10^5
	Btu/h·ft·°F	W/m.K	1.730
	cal/s·cm·°C	W/m.K	4.184×10^2
	Btu/lb·°F	J/kg.K	4.184×10^3
Torque	lb·in.	N·m	1.130×10^{-1}
	lb·ft	N·m	1.356
Velocity	ft/min	m/s	5.080×10^{-3}
Volume	rpm	rad/s	1.047×10^{-1}
	in. ³	m ³	1.639×10^{-5}
	ft ³	m ³	2.832×10^{-2}
	in. ³	mm ³	1.639×10^4
	ft ³	mm ³	2.832×10^7
	gallon (U.S.)	liter	3.785
OTHER CONVERSIONS			
	lb/in. ²	kgf/mm ²	7.030×10^{-4}
	lb/in. ³	g/cm ³	2.768×10
	kg/mm ²	MPa	9.807
	Btu/h·ft·°F	cal/s·cm·°C	4.134×10^{-3}
	ounce	g	2.835×10
	micromin	micrometer	2.540×10^{-2}
	angstrom	m	10^{-10}
	tonne	kg	10^3
	ton	lb	2.240×10^3

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